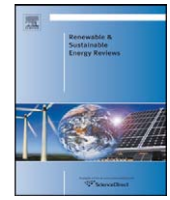
Renewable and Sustainable Energy Reviews 14 (2010) 301–311

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Solar energy development in China—A review

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ARTICLE INFO

Article history:
Received 7 March 2009
Received in revised form 18 July 2009
Accepted 7 August 2009

Keywords:
Solar energy
Photovoltaic
Sustainable development
Application practice

ABSTRACT

The steady and maintainable electric power provides the development momentum of a country's industrialization, which is indispensable to every country at present. It is well known that China is the largest developing country in the world. With the rapid development of economy and society, energy demand of Chinese society is increasing in an incredible speed, i.e., the annual accumulative total capacity of electric energy is about 0.1 billion kW, and the most of them is provided by the fossil fuel resource, and the share is about 90% in China. Certainly, it is a very inappropriate energy structure, so the sustainable development of country is impossible in future, the status must be improved in order to achieve sustainable development. Fortunately, China has large country area, and there are abundant solar resources. Development and application of solar energy have been regarded by the government and ordinary people, and they thought that solar energy can provide more and more electric energy in future, and more and more actual examples have been applied in the last decades, which are supported by central government and local governments. This paper discusses the distribution zone and current developmental situation of solar energy in China. Then, some application practice is described, such as solar energy greenhouse, solar energy hearth, solar water heater, solar lighting system, solar water pump, distributed generation (DG), grid-connect photovoltaic generation (GPG) and wind–solar hybrid system. The policies and law of China central government and local governments are described in the following paragraph. At the end, the developmental prospect of photovoltaic (PV) in future China and the development barriers and recommendations are introduced.

Contents

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doi:10.1016/j.rser.2009.08.005

1. Introduction

Various fossil fuel resources provide the largest number of energy, which is a necessity for the modern industrial economy, such as oil and coal and natural gas. Electric power has become indispensable for almost all human activities. Human activities cannot leave electric power from cooking and heating to industrial production and transportation. Energy has become a powerful engine of economic and social development to every country, and the total wastage amount of fossil fuel is increasing rapidly in whole world. However, with the rapid industrialization of world, the energy crisis is presented in foresee future. The price of oil in world decreases from about 147 dollars to about 60 dollars during Finance Crisis, which has decreased about 90 dollars from the vertex [1]. But with the decreasing of fossil resources, the price of fossil fuel resources must increase in future, certainly which is based on the rapid development of world finance. Once the Finance Crisis is conquered, the energy prices will increase rapidly in an incredible speed. So the maintainable energy development is encouraged by some government during Finance Crisis, such as USA, Japan and China. For example, China is affected by the world finance tsunami, and lots of workers have lost their employment, the amount is about 20 millions [2]. But Chinese government will invest more than 4367 billion dollars to the new energy domain in order to overcome the high energy price in next 10 years, so the nuclear energy and wind energy and solar energy in China will rapid development in the World Finance Crisis [3].

It is well known that China is the largest developing country in the world, and which is the second largest country in energy consumption. The Gross Domestic Production (GDP) of China in 2008 is about 4500 billion dollars, which ranks the third in the world [4]. The GDP of China is almost equal to Japanese GDP, but the energy wastage of China is about 3–9 multiple to compare it with Japan at the same time [5]. For example, the wastage of coal is more than 2.74 billion tons in 2008, and the wastage of oil is about 0.36 billion tons, and natural gas is about 80.7 billion m^3 [4]. The total amount of SO_2 emission from 2000 is more than 20 million tons, which ranks the first in the world [6]. The total amount of CO_2 emission is more than 4.5 billion tons, which ranks the second in the world [7]. The coal in China holds an important station because the coal reserves is abundant in large domain, so the percentages of coal energy in primary energy production and consumption are more than 67% in past 30 years, and then the environment and zoology are polluted in lager domain, and the share of country area is more than 30%, which is vitiated by acid precipitation, and the degenerative area of lawn and soil and forest is more than thousands of hectare, and hundreds of cities are destroyed, and more than 0.3 billion rural population cannot gain the clear drinking water, and more than 0.4 billion urban population cannot gain the fresh air, and the annual finance losing is about 400 billion dollars, and the loss due to pollution in China each year 10% of GDP [8]. The essential reason is the inappropriate energy structure of China, which has brought a series of environmental problems, which has affected the human living. In order to improve the inappropriate energy structure it is important to find an exchangeable energy. So the renewable sources are regarded by Chinese government and ordinary people, such as solar energy, wind energy, tide energy, bioenergy, etc. At present, the renewable sources have been used to various domains, and the application of renewable sources is encouraged by Chinese government. China government establishes Renewable Energy Law in February 2005, and the law is expected to act as the guarantee and special emphasis on the subject of renewable energy development. The renewable sources are expected to play an important role in future energy service. Abundant fund has been invested to the renewable energy domain by Chinese government, such as PV building, Grid-connect photovoltaic generation, wind energy, and the total amount of fund is about 4367 billion dollars [3]. Especially, solar energy has been regarded due to it is renewable, friendly to the environment, distributing abroad, and flexible for installation. Abundant solar energy resource gives a chance to improve the inappropriate energy structure in future China. At present, PV industry has been regarded by the local governments and central government, which have a rapid development speed in recent 10 years, i.e., Wuxi Shang-De in 2005 ranks the fourth in the world and just behind Sharp and Q-cell and Kyocera [9–12].

This article will discuss the current situation and outlook of solar energy applications in China. Firstly, the geographic profile of China and the current energy situation are described. Then, the solar energy distribution and current development and market situation of PV are described in following section. Then, various PV applications in China are introduced, such as solar water heater, solar lighting system, solar water pump, distributed generation (DG), grid-connect PV generation (GPG) and wind–solar hybrid system. The following section introduces the policies and technology and barriers. Finally, the prospect of PV in China is forecasted in this paper.

2. Geographic profile of China

China lies in the northeastern part of East Asia between 4° and 53° North latitude and 73–135° East longitude with an area of 9.6 million km^2, and a population of about 1.3 billion. The Pacific lies in the east of China. The coastal zone of China consists of about 18,000 km coastline. There are more than 15 countries to border on China, such as India, Pakistan, Russia and Vietnam. The country is divided into more than 30 provinces and thousands of cites are located in large soil, and hundreds of mountains ranges laid in the large area from north to south, such as Changbaishan, Taihangshan, Tianshan and Himalayas. And thousands of rivers are distributed in every province, and the Changjiang and Huanghe are entitled the Mother Rivers of Chinese people. The city population is more than 0.5 billion, and there are more than 0.2 billion village people, who work in big city.

3. Current energy situation in China

China has a huge population with abundant natural resources, but the average amount of Chinese people is limited, which is less than 1/2 of world people. Certainly, the annual wastage of ordinary Chinese people is only 1/4 of Japanese people and the share is about 1/12 of USA [13]. But the annual total wastage of energy in

China is enormous because of the huge population, which ranks the second in the world at present. Furthermore, Chinese energy service is highly dependent on fossil fuels in the last 50 years, i.e., coal, oil, and natural gas. According to the reports of Chinese Development and Innovation Committee (CDIC), the coal is the most important fossil fuel resource in China, which is more than a share of 67% in past 30 years. Renewable energy is less than a share of 7%. Oil energy has a share of 23% and the remaining 3% is supplied by natural gas [14]. As mentioned above, the renewable energy has a small share, such as solar, wind, water and bioenergy. The energy service is highly dependent on fossil fuels, and the inappropriate energy structure has a huge negative impact on economy and energy security and environment of the country. At present, thousands of rivers have been polluted, and the serious contaminative amount is more than a thousand. For example, almost all the rivers are polluted in Shanxi Province, and no fish can exist in the contaminative water, and the water of river cannot be drinkable by human and livestock. Taiyuan is the most famous contaminative city in the world, and which is the capital of Shanxi Province, and FenHe is the mother river of Taiyuan. But there are no water in FenHe and as much as all water has been deposited in reservoir in order to provide enough water to townsman. So no fish and no animal can live in the riverside because all of the watercourse is dry. The essential reason is the excessive mine of coal, and the phenomena are familiar in the whole China. The mineral resources of many cities have been exhausted, and the amount is more than 20, such as HuaiBei, TongLing, JiaoZuo and BaiYin. In order to improve the inappropriate energy structure, Chinese government have established some policies to settle the pollution. Unluckily, the inappropriate energy structure of China hardly had any change in the last 30 years.

China has big soil and abundant natural resources, which is written in student's textbook when I am a pupil until recently, and almost Chinese people consider it to be true, but the actual status is the opposite. For instance, China has abundant coal resource, and the theoretic total amount is more than 800 billion tons, which ranks the first in the world, but the average efficiency of coal exploitation is less than 40%. The actual total amount of workable coal is about 114 billion tons. At the same time, the annual amount of coal wastage is more than 2.5 billion tons, and the wastage in 2007 is 2.74 billion tons. In other words, the coal resource will dry up in 2050. China has abundant oil resource, and the known total amount is about 13 billion tons, and the average efficiency of oil exploitation is less than 50%. The remaining workable amount is about 4 billion tons, the annual amount is more than 0.3 billion tons. In other words, the oil will dry up in intending 20 years. Simultaneously the natural gas and uranium can be exploited about 30 years and 50, respectively. At the same time, the structure of rural household energy consumption in China is more unreasonable than city. Studies indicate that the proportions of straw, firewood, and coal consumption in total energy consumption have remained at 88.8–91.0% [15,16]. In a word, China has a huge energy impact, and the impact of economic and society sustainable development is austere in the future. The development of renewable energy must be regarded by governments and ordinary people, or else, the sustainable development is bosh, and the industrialization of China is impossible.

4. Solar energy in China

It is well known that China has abundant solar energy resources in large country. Thousands of years ago, the solar energy was used to insolate the corn and salt and clothing by Chinese ancestor. The easy application is used to improve the life quality of ordinary people until recently, such as solar energy street lamp, solar water pump, solar heater and solar energy charger. At present, the PV industry of China has a huge development in past 10 years. For example, the yield of Chinese PV in 2007 is more than 1200 MW, and which has share of 35% in whole world, which ranks the first in the world [17,18]. Various actual applications have been used to improve the daily life of common people.

4.1. Solar energy resources distribution

According to the data of Chinese Weather Bureau (CWB) and literature [13], the total solar energy resources are enormous in large soil area, but the irradiation is various in different zones. The Tibet and southeast of the Qing-zang altiplano lie in the highest irradiation zone of solar energy, and the annual hours of sunlight is more than 3200, and the annual irradiation amount is about 6600–8500 MJ/m^2. The annual hours of better irradiation zone are about 3000–3200, and the annual irradiation amount is about 5800–6600 MJ/m^2. The available zone is about 2200–3000, and the annual irradiation amount is about 5000–5800 MJ/m^2. The Deficient zone has a share of 33%, and the sunlight hours are less than 2200, and the irradiation amount is less than 5000 MJ/m^2. In other words, the abundant zone of solar energy has a share of more than 67%, so China has abundant solar energy. Certainly, China has thousands of towns and hundreds of cities and the different cities have the different daily irradiations and best obliquities. According to the different latitudes, Chinese main cities have different solar irradiation parameters.

4.2. PV industry development in China

Based on the data of CDIC and literature [17–19], Fig. 1 shows that the yield of solar cell is increasing rapidly in the last 9 years. Fig. 2 shows the PV share of different countries in 2007. The fundamentality of solar energy has been regarded by Chinese government and entrepreneurs in the recent decades. The market share of Chinese PV has increased from 1% to 35% in the last 8 years, and the quality has step up at the same time. According to the data of Germany web news, the total yield of Chinese solar cell in 2007 is more than 1200 MW, which have a share of 35% in whole world, which ranks the first in the world [17,18]. Based on the news of economy daily, the total yield is more than 2000 MW in 2008 [19]. The producer of PV in China is more than one hundred, and the annual yield has a double speed in past 6 years. For instance, the yield of Wuxi Shangde in 2005 is 82 MW compared with 158 MW in 2006, and which ranks the fourth in the world and just behind Sharp and Q-cell and Kyocera. Simultaneously, the total yield of world PV is 3436 MW in 2007, and which increases of 56%. The production of Chinese industries increases the share from 20% to 35% in 2007, which ranks the first in the world. As we can see from Figs. 1 and 2, the development of PV industry in China is rapid in the recent decades. The market share is express increasing in past 5 years. At present, more and more Chinese enterprisers begin to invest the PV industry. Certainly, the PV industry of China faces some difficulties at present, such as the technology of produce, raw

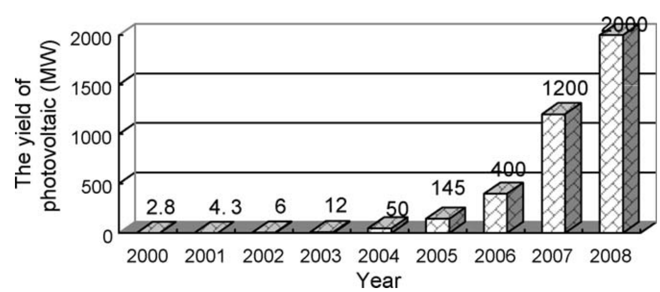


Fig. 1. The yield of solar cell in the last 8 years (Source: CDIC and [17–19]).

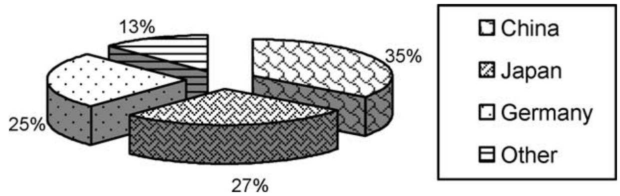


Fig. 2. The PV share of different country in 2007 (Source: http://www.sxcoal.com/energy/2008/04/07/91317/Article.html) [17].

Table 1
Market shares of different PV applications in China, *Note*: (Source: Chinese Environmental Science Press) [12].

Classify	The accumulative total (MW)	Market share (%)
Electric energy supply of remote villages	33	41.3
Communication and industry	27	33.8
Solar energy manufacture	16	20.0
Architecture PGEP	3.8	4.8
Large-scale desert PGEP	0.2	0.3
Total	80	100

Note: (Source: Chinese Environmental Science Press).

and processed materials and environmental pollution. The PV is produced in some factories, and the number is more than one hundred. But most of them are nothing more than assembling the subassembly of PV. There is no little technology, and the benefit of economy is bad. The essential reason is no pivotal technology, such as silicon material, incision, forging and polish, etc. It is well known that the produce of PV products has a lot of contamination, such as acidic and alkaline waste water, heavy metal waste residue, which have big effect to local environment.

4.3. PV market development in China

At present, the PV market in China is mostly used to the electric energy supply of remote villages and communication and solar energy manufacture and PV generating electric power (PGEP). Some productions are used to improve the daily life of common people, such as solar energy street lamp, solar energy lawn lamp, solar energy traffic signal lamp and solar energy sight lighting. The grid-connect energy production is located in demonstration moment due to the costly price of PV generating electric power. Table 1 shows the market share of different PV applications until 2006. Fig. 1 shows that the development speed of PV in China is unbelievable rapid. However, Table 1 shows that a very small market of Chinese PV exists in 2006, and the accumulative total of PV is fixed only 80 MW in the last 30 years [12]. The installation total of PV is 20.3 MW in 2002, and the annual total of other years is less than 10 MW. Fig. 3 shows the development of Chinese PV market in the last 30 years, and the units are KW [16]. As shown in Fig. 3, the market is impossible to contain the yield of Chinese PV. Mostly the share of PV is exported to the developed country, such as Germany, Japan and USA. The share of domestic market is less than 1%. Draw a conclusion, the PV market of China must be enlarged in order to contain the yield of Chinese PV and the PV manufactures [9–12].

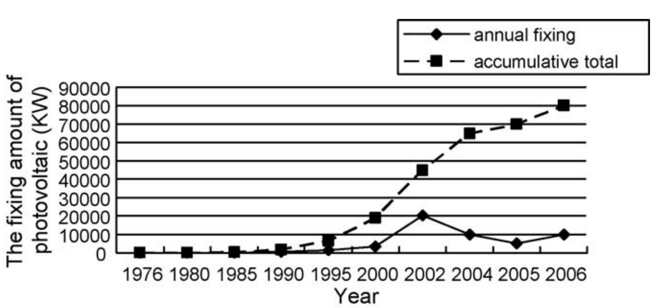


Fig. 3. The accumulative total and annual fixing of PV in the last 30 years [16].

5. Solar energy applications in China

Thousands of years ago, the solar energy is used to insolate the corn and salt and clothing by human. One thousand year ago, the coppery concave mirror is used to obtain fire by Chinese ancestor, which is collected from spring and autumn to Song dynasty by Chinese museum [13]. But the easy use of solar energy in China is not change until 1971, and the first application of PV is utilized to the power supply of secondary planet by Chinese scientist. The PV is first utilized to the ground in 1973. By the past 30 years, there are many applications for the direct and indirect utilization of solar energy, and the application domain of solar energy is increasing rapidly with the development of China, Such as solar water heater, water pumping, road lighting system, solar heating buildings, solar refrigeration, air conditioners and PV generation system. In China, mostly the solar energy is used by the solar water heater and solar energy greenhouse. The extensive utilizations of solar energy have brought great environmental and economic benefits in the recent decades. The utilizations of solar energy can be divided into two kinds. One is the application of solar energy heat, which can be divided into the direct and indirect utilization of solar energy heat. Such as solar energy hearth, solar energy house and solar energy greenhouse, there are the direct utilization of solar energy heat. The indirect utilization in China includes some domains, such as solar energy desiccation (SED), solar energy calefaction of industry (SEC), solar energy refrigeration of industry (SER) and solar energy heat generate electricity (SEHGE) by using solar energy collect heater. The other one is PV generation electricity, which is used to generate electricity by solar cell. Certainly, there are many utilizations in China, such as space domain, navigate assistant of sea, wireless communications, portable power supply, cathode protection, PV water pump and lighting. The application practices of solar energy in China are described in the section.

5.1. Direct utilization of solar heat

5.1.1. Solar energy greenhouse (SEG)

There are more than 0.8 billion farmers in China, the average soil is less than 0.2 ha, and the annual earning of an ordinary people is less than 200 dollars if the soil is used to cultivate corn. In order to improve the earning of family it is important to change the breed of cultivate land for an ordinary farmer. There is more than thousands of SEG in Chinese villages, and the annual economy benefit of a greenhouse is about 1000 dollars, and the area is not more than 300 m^2. It is well known that China is the largest developing country in the world, and in order to realize the industrialization of Chinese society it is important to improve the living standard of ordinary people, which is the important target of central government at present. The earning of farmer is low compared with the city people, and the greenhouse can improve the earning of numbers of farmer, and the daily life of city people is improved because of thousands of tons green vegetable is afforded. At present, abundant green vegetable is afforded by greenhouse in winter, and the amount is enough for every people, and thousand of tons vegetable is exported to developed country, i.e., Japan, Korea and Russia. The vegetable in winter include white potato and cabbage for ordinary people in 1980s, the amount of green vegetable is very lack, and the price of green vegetable is very

costly, which can provide only a little people. The amount of greenhouse in China is increasing rapidly with an incredible speed in recent 30 years, the daily life of common people is improved and the earning of farmer is increased by using greenhouse. Moreover, the greenhouse is used to breed the flower and seedling, i.e., rose and lily and azalea. More and more common people purchase the fresh flowers in order to improve the quality of life. At present, numbers of fresh flowers is export to developed country, thousands of foreign exchange is paid to the common farmer. Certainly, SEG is the broadest use of solar energy heat in China.

5.1.2. Solar energy hearth (SEH) and solar heating building (SHB)

According to the literatures [15,16], the proportions of straw, firewood, and coal consumption in Chinese village total energy consumption have remained at 88.8–91.0%, and the energy share is about 50% which was provided by country. So thousands of trees are lopped and thousands of tons of straw are burned, atmosphere and zoology are polluted in large domain. In order to improve the condition it is important to find replace energy, such as firedamp, solar energy and wind energy. At present, the SEH has been used to cook for remote zone, which can focus the solar irradiation and solar heat to the boiler. One SEH can economize about one ton straw per annum, and the section of SEH is 2 m^2. The accumulative amount of SEH until 2002 is more than 300 thousands, and the heat efficiency is about 50% [13].

Moreover, the direct solar heating has been applied to SHB at present. There are more than 0.6 billion people living in North China, and the domain needs to provide heat in winter, and the time is more than 5 months in most of the domain. According to the statistical data, one m^2 of building need about 30–40 kg coal in China in order to keep room temperature, and most of them provided heat by using the boiler, so millions of tons of coal is burnt and millions of tons exhaust gas is let to air, i.e., CO_2, SO_2, NO_x. Certainly, the central government has realized the question, and thousands of solar heating houses have been build in northeast and northwest and north China. The area is more than 10 million m^2 till 2000, and 1 m^2 can save about 20 kg coal. Draw a conclusion, the SHB can save abundant of fossil resource and no exhaust gas is let, so SHB has a big future in future China. Certainly, the number of SEH and SHB is very little, and the environment benefit is very little at present [13].

5.2. Indirect utilization of solar heat

5.2.1. Solar water heater (SWH)

Chinese government and people realize that the solar energy is significant to play an important role in total electrical energy demand. The most extensive indirect utilization is solar water heater, which is broadly utilized to every community in China, and the new total amount of solar energy water heater in 2005 has a share of 77.3% in the world, and China has become the biggest solar water heater production, sale and holding country in the world. The accumulative area in 2006 is more than 100 million m^2, and the new incremental area is 20 million m^2. Fig. 4 shows the holding accumulative total and annual yield of SWH in the last decades, and the unit is million m^2. The above data based on CDIC [11]. The holding rate of water heater in Chinese big city community is more than 70% at present. However, the SWH in China has a share of 1% in 2007, and the very low share in vast village and small city community is the main reason. For example, some villages use the solar heat by a black water tank (BWT), which can be used in summer, and the time is limited in 20:00–22:00. The gas and electric water heater have a big share in many cities. The essential reason is the high value of SWH for the common people. The value of BWT in China is about 20 dollars, and the value of electric water heater is about 50 dollars, and the value of gas water heater is about 100 dollars. The value of solar water heater is about 200 dollars at the same time. In my opinion, the SWH in China has a big development foreground because of which is green and clear and sustainable. Further more, gas and electric water heater is not security, which causes some person accidents in recent years, and the annual amount of death is more than 20. With the rapid rise of the energy price in future, SWH has better competition and is more popular compared with conventional gas combustion and electric-driven water heaters. More and more townspeople enjoys SWH because of it is green and convenient. Chinese government encourage the use of SWH, and the object area of SWH in 2010 is 0.15 billion m^2. In a word, the SWH in China has a beautiful future.

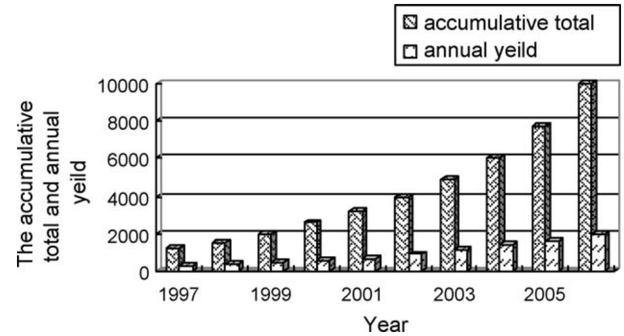


Fig. 4. The holding accumulative total and annual yield of SWH (Source: CDIC, 2006) [11].

5.2.2. SED and SER and SEHGE

Thousands of years ago, our ancestor desiccates the food and cloth by using the solar energy, which is the broadest and most centuries-old method of solar energy use in human history. Until today, billions of tons corn in autumn of China is desiccated in road and rooftop and everywhere by using solar energy. But the direct solar energy use have some disadvantage, such as bad efficiency, long time, big dust and unsanitary, and the rain and insect can effect the quality of corn. So the SED has been used to desiccate the corn and food and Chinese traditional medicine, which have improved the use efficiency of solar energy. The actual examples have been reported in everywhere of China, which refer many domain, such as eatable, wood, industry, and Chinese traditional medicine. An actual example, a unitary SED system has been established to desiccate the Chinese date and dried fruit and Chinese traditional medicine in Guangdong Province, and the section is 187 m^2, and the daily amount of materiel is about two tons, and the hydrated share is decreasing from 40% to 15%, and the maximum efficiency of solar energy can reach about 60%. SED is used to desiccate pod in Sichuan Province, and the section is 120 m^2, and the daily amount of materiel is about 1 ton. Certainly, SEC has been used to heat up the industry production at present, which can save part of the energy, i.e., it has been used to heat the meat, food and water in some eatable industry [13].

It is well known that China has the biggest building area in the world, and the area is more than 40 billion m^2. Based on the statistical data, the energy wastage of building has a share of 25% in the whole energy wastage. Specially, some industry production is stopped in summer in order to provide enough electric energy to common people, and the electric energy is used to air condition, and the economy loss is more than one billion dollars. Fortunately, the most of the domain in China has abundant solar energy, and the solar energy heat is used to provide the energy of SER. At present, some actual examples have been used to improve the electric energy quality. An actual example has been established in Shandong Province Rushan by Beijing solar energy graduate

school, which is used to provide part energy of park. Another actual example is a big air condition and hot water system in Guangdong Province, which is established by Chinese science academy, which can provide all-year hot water to the whole edifice, and which can provide the cool air by using the solar energy air condition [13].

The theory of SEHGE is parallel with the coal generate electricity system, and the solar energy is used to heat water. Then the high temperature and high vapor pressure is used to drive steamer. Finally, the steamer produces the electric energy by driving the motor. But the primal energy is different during the generate electricity course. Some specialists of developed country have established a lot of actual examples in the last 30 years, such as USA, France, Japan and Germany. But the use of SEHGE in China is a little, and some universities and graduate schools establish simulation equipment, and the single amount of equipment is less than 2 kW [13].

5.3. PV utilization

The pioneer application of PV in China is utilized to the exploitation of space domain by Chinese scientist due to the price of PV is very costly, such as which is used to the power supply of secondary planet and spacecraft, and the weight of PV has a share of 10–20% of the whole secondary planet weight, and the price of PV has a share of 10–30% of the whole secondary planet price. So the weight and price of PV must be decreased in order to decrease the launch price of secondary planet, which is the research direction of space application in future. PV has been used in various domains with the development of economy and society at present. Sea sail assistance is very important to instruct the sail direction of ship. If the load of system is enough small, the efficiency of system is enough high, which can be provided the power supply by the PV, and the cost is decreasing with the technology progress. Now the PV system has been used to the wireless communications in remote zone and carry-home PV power supply and cathode protection and commodity. The most broad application practices of PV in China are described in the section.

5.3.1. The city road lighting system

It is well known that hundreds of big cities lie in the large soil of China, and there are more than 10 million street lamps in those cities. The annual total amount of whole city road lighting system is more than one billion degrees, and billions of dollars is expended in order to pay the expense of electric power, which had became the enormous burden of the Chinese government. The abundant primary resource is consumed at the time, and the wastage of coal is more than two million tons, and a mass of CO_2 and SO_2 and NO_x are vented, and a mass of castoff pollute the environment and water and air. Fortunately, the problems have been considered by the Chinese central government and local government and ordinary people. The solar energy is utilized in the city road lighting system by some local governments in order to improve the local environment, i.e., solar energy street lamp, solar energy community lighting and solar energy scenery lighting. The solar energy street lamp has better competition and is more popular. More and more cities in China begin to replace the conventional street lamp by using the solar energy street lamp. For instance, there are more than 3000 solar street lamp by using the city lighting system in Binzhou. The whole street lighting system is replaced by using the solar street lamp in Linan, Zhejiang Province. Moreover, the annual electric power cost of conventional street lamp in Hangzhou is 0.3 billion RMB. It is estimated that the investment of solar LED street lamp is equal to the conventional lighting system during 3 years. The great economy income is received from the renewable solar street lamp during the remaining years. Synchronously, the enormous income of environment is gained.

Other solar energy lighting systems have been used to improve the life of common people, such as court lighting, lawn lighting and scenery lighting. The solar lighting systems improve the habitation and life quality of citizen, which brings the enormous environment and economy benefit. For example, the solar street lamp is used to improve the lighting condition of Shitai freeway in 2006, and the total investment is more than three million RMB. The total of traffic flux is increasing 13% compared with the corresponding period of last year, and the annual total of traffic accident in winter is decreasing from 50 to 25, and the economy loss is decreasing from 2 million RMB to 12,000 RMB, and the total of injured people is decreasing from 41 to 25 at the same time. Moreover, the scenery lighting is used to improve the sight of hilly country park in Xiamen, and the total of solar scenery lamp is more than 200. The lighting system of remote village in Yangzhong is achieved by using the solar street lamp. As mentioned above, the requirement of solar street lamp is enormous with the sustainable development of China in future.

5.3.2. Solar water pump

West zone of China include Tibet and Sinkiang and Qinghai and Shanxi and Gansu and Sichuan, which is the best underdeveloped zone in the whole China, the economy and zoology is very brittle. And the area of West zone is more than 4 million km^2, and the population is more than 0.2 billion, and the zone contains abundant natural resource. Unluckily, the water is exceeding lack in the northwest zone of China, and the desert zone of northwest China in 2007 is more than 1.3 million km^2. Based on the data of Chinese forest bureau, the annual increscent desert area in 2001 is more than 2000 km^2. For instance, Sinkiang Province lies in the northwestward of China, the area is more than 1.6 million km^2, and the natural resource is abundant. But the Takelamagan desert lies in the middle part of Sinkiang Province, and the area is more than 0.33 million km^2, and Sinkiang divides into 2 parts. Fortunately, Chinese central government and local government have realized the problem of increasing desert area, and some actual actions have been implemented to improve the environment and zoology of northwest zone. And the groundwater of desert zone is abundant in Chinese northwest zone. The groundwater gives a hope to banish the desert. Some electric power is used to pump groundwater by using water pump. As mentioned above, the environment and zoology is very brittle, and the desert zone is far away from main power lines, and the traffic is not convenient. Simultaneously, the high solar irradiation exists in the large northwest zone. The solar water pumping has great potential to banish the desert and improve the irrigation area of northwest farmland. Some actual applications have been used to improve the zoology of northwest and traffic, such as the desert road, protect desert oasis and solidify desert. For instance, the Talimu desert road is laid to link the north and the south of Xinjiang Province in 1995, and the length of desert road is more than 550 km. At present, more than 5 desert roads have been laid in the last 20 years.

In an example of solar water pump application in remote villages of northwest China. The area of grassland in China is more than 0.4 billion hectares. The area is 0.102 billion hectares, which is irrigated by local people. However, the environment and zoology of Chinese northwest are brittle due to the annual rainfall is less than evaporation. The area of desert is increasing in the last 50 years, and the total of desert area in 2007 is more than 1.3 million km^2. The water pump for irrigation is used to improve the local environment by local people. It is well known that the economy of Chinese northwest is very poor, and the local people cannot support the costly fee of diesel water pump, and the diesel oil will destroy the brittle zoology of northwest. In other words, solar water pump gives a hope to the people to improve the local

zoology. But the solar water pump has a higher price than the diesel water pump. Fortunately, the central government and local government give some assistance to increase the popularization of solar water pump. An actual solar water pump system is described in the section, which lies in Neimenggu Province. The end user' name is Nashun, and the grassland area of family is 5.3 ha. The system contains: a well, a PV, a water pump, a converter/inverter and some sprinklers. The capacities of PV and water pump are 3 kW and 500 W/24 V, respectively. The total of investment in 1999 is more than 60,000 dollars. The total of livestock is more than 370 by using the solar water pump. In China, the irrigation area of solar water pump in 2003 is 534 ha. The object area in 2010 is more than 392,000 ha, and the need of PV is more than 261 MW. As mentioned above, the prospect of solar water pump in China is great in future [20].

5.3.3. Distributed generation (DG)

The large-scale distribution network (LSDN) is considered by Chinese government in past 30 years, and the accumulative total amount of electric energy in 2007 is more than 0.713 billion kW. However, a potential danger exists in the LSDN because the modern people are more and more dependent on the electric power supply. If an electric network occurs an accident, which will affect the daily life of millions of people, and the unpredictable accident will stop the factory production and the society movement because the electric power is cut. For an instance, the northeast of USA and the east of Canada are cut the electric power by an unpredictable electric network accident in 2003 and more than 50 million people are affected during the power cut, and the daily economy loss is more than 30 billion dollars. So a credible power supply must be found in order to conquer the unforeseen accident. Fortunately, the solar energy is not big affected in the natural disaster and accident. And a solar distributed generation can partially afford the electric supply. With the improvement of people life, more and more people and Chinese government have realized the important of DG to improve the security of electric power supply. For instance, millions of cattle farmers working in the widest northwest zone of China, the herd and cattle farmer will move with various seasons. Because the browse zone is far away from main power lines, so they can conveniently gain the electric power by using the small DG units. In a word, the DG is important to improve the security of electric power supply and the life quality of common people.

Some actual applications have improved the life of ordinary people, who located in remote villages of Chinese northwest zone, such as mobile vehicle of power supply, region power supply and no watch transformer substation. For instance, the DG has been used to the national defence of China. It is well known that China has more than 5000 islands, which intersperse among the 3 million km^2, and mostly the island is garrisoned by the People Liberation army (PLA). Thousands of PLA garrison the island in order to safeguard the coastal areas and territorial seas. But the life condition of PLA is very hardy due to the area of most of the islands are very small, and where they have not fresh water and fossil resources. Fortunately, the small islands have abundant solar and wind resources. The DG is the best way to improve the life quality of PLA and the islander. The PV DG and wind DG and solar–wind hybrid DG have been used in thousands of island army. Some other actual applications have improved the life of soldier and islander. At present, the seawater is desalted in order to provide enough drinking water, and the electric power drive thousands of martial equipment, such as radar, computer and missilery. Certainly, the standard of living is increasing by using the DG. In an example of no watch transformer substation and railway station in Tibet of China. In 1 July 2006, the Qing-zang railway is established from Xining of Qinghai Province to Lhasa of Tibet by thousands of worker, and the length is 1956 km, where we have execrable environment and far-flung winter. In a word, the solar DG has great potential in future China.

5.3.4. Grid-connect PV generation (GPG)

At present, the grid-connect PV generation (GPG) is regarded by the developed country in the recent decades. Fig. 5 shows the increasing shares of GPG in the world. The GPG has a biggish share in the whole yield of PV, and which will achieve a great development in future. However, according to the data of Table 1, the development of GPG in China is very slow, and the market share is only 0.3% in the last 30 years. The essential reason is the costly electrovalence of PV. At present, the electrovalence of PV is about 0.6 dollars per degree, and which is too high to support by the common people. Because of the electrovalence of the conventional fossil resource in China is only 0.5 RMB. Fortunately, Chinese central government had realized the problem, and some hortative policy is established, such as the generating electric power of PV must be accepted by Power Company, and the price is enhanced in order to ensure the advantage and enthusiasm of investors.

The desert zone of northwest China in 2007 is more than 1.3 million km^2. The capacity total of PV is 100 MW per km^2. If the fixed PV area of desert has a share of 1%, and the capacity total of PV is 13,000 GW. In other words, the capacity is double compared with the accumulative total of electric power at present. With the improvement of technology and the decreasing price of PGEP, the prospect of large-scale desert PGEP is enormous in future China. At present, three PV power plants establishing in west desert, the capacity is more than 20 MW. The object capacity of the desert PGEP is 200 MW in 2020. For example, Yangbajin desert PGEP is established in Tibet, the capacity is 100 kW.

The architecture area in China is more than 40 billion m^2, and housetop area is more than 4 billion m^2, and the area of southerly wall is more than 5 billion m^2. The total area can be utilized more than 49 billion m^2. If the fixed PV area of architecture has a share of 20%, the capacity total is 100 GW. Some actual applications of architecture PGEP have been implemented, such as solar energy demonstration city in Baoding, the international flower garden in Shenzhen and the Olympic Games gymnasium in Beijing.

Fortunately, the GPG have been regarded by the central government and some corporations. The biggest GPG in China lie in Dunhuang, Gansu Province. The total capacity is 10 MW and the total investment is more than 73 million dollars and the area of PV is about 1 million m^2 and the annual accumulative total of electric power is about 16 million kWh. The item has a short transmission distance, and the distance is about 13 km from Dunhuang city, which can provide clear energy for common people of Dunhuang. Certainly, some actual examples have been used to improve the energy structure, such as the total capacity of Chongming Island item in Shanghai is 1 MW and the total capacity of Eerduosi item in Neimenggu Province is 255 kW. So the GPG in China has a beautiful future with the increasing regard by the central government and common people [21].

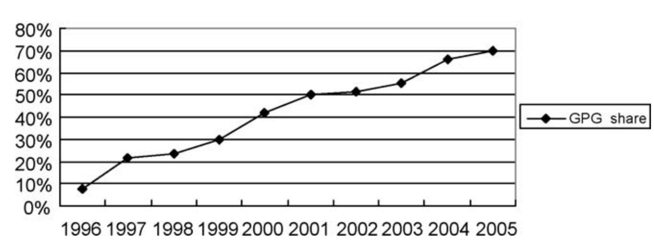


Fig. 5. Increasing shares of GPG in the world (Source: International Energy Sources Office, PV item bulletin in 2006 [12]).

5.3.5. Wind–solar hybrid system

At present, Chinese central government and local government have established more than 300 stand-alone renewable and sustainable electric stations, such as PV generation and wind generation and small waterpower. Especially, PV generate electricity have improved the quality of life of remote villages' people, and which increase the earning of family. However, the stand-alone PV generate electricity system has a common drawback, and the output electric power of PV is unpredictable under tremendous changes in climatic conditions. Fortunately, the hybrid system can partially overcome the problems. Some hybrid methods have been used to improve the quality of electric power, i.e., the wind–diesel, diesel–solar and wind–solar hybrid systems. China has abundant wind resource in large soil, and the northwestward and the seaboard have the best wind energy. Moreover, very good compensation characters are found between solar energy and wind energy. Consequently, the hybrid system has greatly improved the quality of electric power at all time, and the higher generating capacity factors are achieved under unpredictable climatic conditions. The application of wind–solar is regarded by the common people and government, and some local government has replaced the conventional city lighting system by using wind–solar street lamp, and wind–solar hybrid DG is used to supply electric power in remote villages. However, the holding rate of wind–solar hybrid street lamp is less than the conventional street lamp at present. The primary reason is the costly price of hybrid system. For example, the price of wind–solar hybrid street lamp is more than 4000 dollars, and the price of conventional street lamp is about 2.2 thousand dollars at the same time. Certainly, the price will descend with the improvement of technology, and the wind–solar hybrid system still has great potential in future [22].

6. PV technologies

With the rapid rise of the energy price, the application of solar energy is accelerating, and the great environmental and economic benefits have been brought by using the PV. Some hortative policies are formulated by the central government and operated in the whole nation. Hundreds of manufactories have produced millions of PV equipments in the last 5 years. Certainly, the development of PV system is puzzled by some problems at present. It contain: (I) the maximum power point tracking (MPPT) control method is very important to track maximum power point of PV. Different control method brings different output efficient and different PID parameter setup brings different output result. In order to improve the conventional PID controller it is important to use some intelligent control method, such as Fuzzy, Nerve Network (NN), Immune and Robust. (II) An efficient MPPT algorithm is very important to increase the output power of PV system. At present, many MPPT algorithms and control schemes of PV generate system have been proposed in existing literature, but the efficiency of MPPT algorithms is relatively low. So the price of PGEP is very costly because the specialists cannot find an efficient MPPT algorithm and control method at this time of day. (III) The DC/DC circuit topology can track the maximum power point (MPP) of PV system. The conventional Buck and Boost and Bust-Boost circuit be used to acquire the MPP of PV, but the efficiency is low during the track MPP course. At present, the efficiency of converter is less than 90%, and the loss is flagrant due to the PV has a costly price. Moreover, the new grid-connect technology and topology must be found in order to export maximum power from the PV, such as Matrix Converter should be thought to use the PV system, which have been used to the grid of wind turbine at present. (IV) The charge and discharge management of storage battery must be considered. The characteristic of storage battery should be researched to improve the capacity of charge and discharge. Some charge methods have been described in existing literature, such as the constant voltage (CV) method, the constant current (CI) method, the combined method of CV and CI, three stage charge method, two charge method and intelligent charge method. The research of discharge method is neglected because most of the experts regard the charge method of storage battery. Certainly, the pulse discharge method and little big current discharge method have been described in some literature. (V) The PV material technology must be regarded because different materials bring different output efficiency and output power under same area conditions. Moreover, it is a pivotal question to decrease the price of PV and the electrovalence of PGEP. Unluckily, the price of PV is costly and the output efficiency is low at present. So the material technology must be improved in order to acquire low-cost PV.

Many MPPT algorithms and control schemes of PV generate system have been proposed in the literature [23–27], i.e., a cost-effective single-stage control scheme is proposed in the literature [23], it proposes a cost-effective single-stage inverter with maximum power point tracking (MPPT) in combination with one-cycle control (OCC) for PV power generation. A comparative study of the maximum power point trackers using a switching-frequency modulation scheme (SFMS) for PV panels is presented [24]. Method of locating the maximum power point (MPP) is based on injecting a small-signal sinusoidal perturbation into the switching frequency of the converter and comparing the ac component and the average value of the panel's terminal voltage. The linearity method is a novel method in order to track the maximum power point [25,26], the proportionality coefficient of the prediction line is automatically corrected using the hill-climbing method when the panel temperature of the solar arrays is changed. The Fuzzy method is described in the literature [27] that focuses on the nonlinear characteristics of solar cell. Some other pivotal technologies have been analyzed in existing literature [28–32], i.e., an integrated electricity production cost analysis for autonomous electrical networks based on renewable energy source and energy storage configurations is presented in the literature [28], energy storage systems basic parameters and production cost evaluation model and two representative cases are described in the paper. The radiation model for the major solar and thermal climate zones is described in literature [29], and regression techniques and artificial neural networks were used to investigate the correlations between daily global solar radiation and sunshine duration for different climates in China. Optimal size of battery is an important technology in the renewable system, which decides the investment and life span of stand-long renewable generation system. The literature introduces the optimal sizing of battery-integrated diesel generator for remote electrification through design-space approach, and optimum system configuration is identified based on the minimum cost of energy through optimal dispatch strategy [30]. The optimization of wind-solar-battery hybrid system is introduced in literature [31], and the sizes of wind machine and solar panel and batteries are estimated to optimize hybrid system and cost. Certainly, some actual instances of PV generation are described by numerous experts and literature, such as an energy loss experimental study of PV and solar thermal hybrid system is described in literature [32]. As mentioned above, various literatures have proposed some MPPT algorithms and control method, but no one can efficiently track MPP till now. If an efficient MPPT method is discovered in future, which will impulse the rapid development of PV industry, and the popularization of PGEP will be accelerated in foreseeable future.

7. Renewable energy policies in China

The renewable energy has been regarded by the Chinese government in the past 10 years, and the Chinese Renewable Energy Law had been confirmed by the Chinese government in 28

February, 2005. In order to achieve sustainable development in future, the Chinese government formulates a series of policies and regulations to encourage renewable energy utilization. The correlative items contain: (I) all PV electric power should be purchased by Power Company, and which should provide enough grid-connect service. (II) The electrovalence is established more than conventional price in order to encourage the development of solar energy, the benefits of investor should be ensured. (III) The central government gives some allowances to the renewable resources industry. (IV) The central government encourages the renewable resources DG in order to improve the electric power serves of no electric power supply region, and the early investment and medium-term maintenance are afforded by central government. (V) Although the end user uses the electric power from PV generation, but the electrovalence of end user is same compared with the end user who use the conventional electric power. As mentioned above, the central government of China regards the development of PV in order to improve the unreasonable energy structure. More and more hortative policies will be formulated in the foreseeable future. The development prospect of renewable resources is enormous in future China. For an example, the biggest PV generation item in China is Dunhuang GPG, Gansu Province. The owner of GPG has a might of concessionary prosecution, and the time is 25 years [21].

8. Developmental barriers

At present, the development of Chinese PV industry is rapid, and the regard of common people and central government is increased, and the technology is improved. However, policy barrier and financial barrier and market barrier and technology barrier have obstructed the rapid development of PV industry in China.

Firstly, the hortative policy has been established by the central government, but the policies are difficult to implement by local government due to the behalf of local government cannot be ensure. So there is very little actual action to actualize for the renewable energy development. There are more than 30 provinces in China, and different provinces have different impetus of application renewable energy because different provinces hold different natural resources. For example, some west and north provinces have enough fossil resources, the impetus of exploitation renewable resource is small. On the contrary, the east and south provinces lack the fossil resources, and they regard the development of renewable energy, such as sea wind, solar energy and tide energy, and the impetus is big compared with west and north provinces. Furthermore, the policies and regulations of the central government can be rejected by local governments. Certainly, the impetus of west and north provinces is increasing in recent decades because the inappropriate energy structure aggravates the local environment pollution, and which is impossible to achieve the sustainable development of economy and society.

Secondly, the development of PV industry is in need of abundant money, and the price of PV is costly, and the ordinary people cannot bear the cost of PV. For example, the price of a degree electricity is 0.5 RMB at present, and the price of PV generate electricity is more than 5 RMB. In other words, the financial help of government is necessary in order to implement the sustainable development of PV industry. The big grid-connect PV generation should be established in the northwestward desert of China, which requires huge government investment. The biggest GPG item had been established in Dunhuang, Gansu Province. Moreover, the cost electrovalence is about 0.1 dollar due to the price of multicrystal silicon is decreasing from 500 dollars to 100 dollars per kilogram. Certainly, the local government invests billions of dollars in renewable resource in order to improve the zoology of local region and the development potential in future, and there are about 150 billion dollars to invest the renewable resource region by the central government in future 5 years, and billions of dollars of civilian capital is invested the resource region. So the capital is not a barrier of renewable energy development in future.

Thirdly, Table 1 shows that the market of PV application in China is small at present. A small domestic market cannot contain the annual yield of PV. For example, the total yield of PV in 2008 is about 2000 MW, but the domestic PV production has a very little yield, and the annual total is less than 10 MW in the last 10 years. The costly price of PV production is the one essential reason, which exceeds the purchase power of common citizen. Especially, the grid-connect PV generation (GPG) is not regarded by the central government and local governments. The other one essential reason is no novel and applied productions, such as PV reading lamp, PV charger and PV fanner, etc.

Finally, the technology of PV in China is not regarded by government and the experts and university and graduate school at

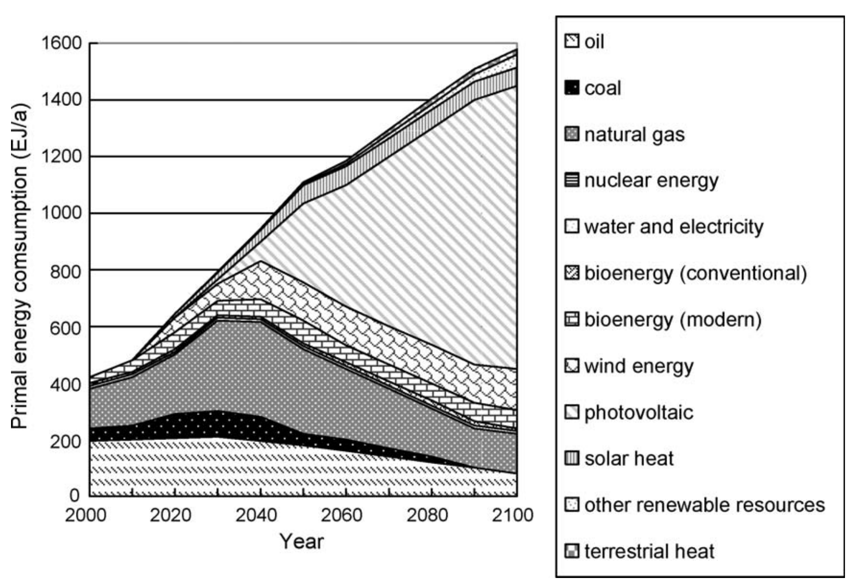


Fig. 6. Prospect of renewable energy in whole energy structure (Source: "European Roadmap for PV R&D", European Commission Joint Research Center, 2004 EUR 21087 EN) [9].

Table 2
The programming and forecast of renewable energy in future China. *Note*: (Source: Renewable energy development item office in China) [9].

Year	2004	2010	2020	2030	2050
Small water and electricity (MW)	34,000	50,000	75,000	100,000	200,000
Wind electricity (MW)	760	5,000	30,000	100,000	400,000
biology energy electricity (MW)	2,000	5,500	20,000	50,000	100,000
Photovoltaic electricity (MW)	65	300	1,800	10,000	100,000
The share of renewable energy (%)	6.5	10	16	20	30

Note: (Source: Renewable energy development item office in China).

present, and the technical investment is not enough in that it is impossible to exploit the pivotal technology. The interrelated technology of renewable energy is not given a course in Chinese university, and no interrelated student graduate from the renewable region. The person with the ability of renewable energy region is not cultivated in company and corporation.

9. The prospect of solar energy in China

At present, the PV generation of the whole world has a little share in the total of electric power system. According to the forecast of Europe Joint Research Center (JRC), with the increasing price of traditional energy, the energy structure of whole world will change in future. It is estimated that the renewable resources in 2030 has a share of 30% in the whole energy supply, and the PV generation has a share of 10% in 2030. The renewable resources in 2040 have a share of 50% in the whole energy supply, and the PV generation has a share of 20% in 2040. At the end of 21st century, the renewable resources have an incredible share of 80%, and the PV generation has a share of 60%. Fig. 6 shows the change of renewable resources in whole energy structure. As mentioned above, the energy impact of China is more austere than the impact of world in the future. In order to settle the austere impact of economic and society sustainable development it is important to increase the share of PV generation in the whole energy supply. At present, PV generation in China has a share of 0%. Fortunately, the government has realized the importance of PV generation, and some intending objects have been established in the strategic programming of Chinese renewable resources exploitation from 2006 to 2020. According to the data of CDIC, the object of renewable energy development in 2020 contains: the large water electric power is 0.3 billion kW, wind energy is 30 GW, solar energy PV generating system is 1.8 GW, the biology energy is 30 GW, solar water heater is 0.3 billion m^2 and the biology fuel is 15 billion liters. In 2050, the renewable energy has a share of 25% in the whole energy supply, and the PV generation has a share of 5%. The capacity of PV generation is 100 GW in 2050. Table 2 shows the programming and forecast of renewable energy in future, and the big water and electricity is omitted. As shown in Table 2, the prospect of PV is enormous in future. The developmental speed of renewable resources is rapid in future China.

10. Conclusion and recommendations

This paper presents the distributing and development and application and prospect of PV in China. In order to conquer more and more energy pressure in future and the rapid increased energy need of Chinese economy, some hortative policies are established by central government and local government at present. With the decreasing price of PV, it can be predicted that the utilization and the production of PV will increase rapidly in foresee future China. Consequently, in order to achieve the sustainable development it is important to regard the solar energy by the central government and local governments. Furthermore, the purchasing power of common people will increase rapidly with the booming development of Chinese society in future, which induces the need of renewable energy production with an incredible increased speed. Certainly, the price of PV production need distinct decreasing by improved technology in the foresee future.

Solar energy resource in China is abundant in large soil. The best utilization of solar energy in Chinese city is solar water heater, which is used to millions of communities in China, and the share ranks the first in the world. The best utilization of solar energy in Chinese village is solar energy greenhouse, which is used in thousands of village in China, and the economy behalf is more than 10 billion dollars, and millions of farmers profit from the use of SEG. Moreover, some other PV productions have been utilized in China. For instance, the stand-alone solar lighting and the hybrid lighting system have been used to city road lighting by hundreds of Chinese cities. The solar DG and solar water pump have been used to supply electric power in remote villages. The PV commodities have come into the market, and the price is decreasing, and the competition of PV productions is increasing, and which is more and more popular by the common people. It is predicted that the solar energy has a big potential in future China.

The Chinese central government has established some hortative policies and laws in order to improve the inopportune energy structure and sustainable development. However, the obvious policy barrier and economy barrier and technology barrier and market barrier for the PV are existent at present, which need the strongly financing support and policy support of central and local government in order to conquer the barriers. The following measures are especially recommended in this regard:

(i) The applications of solar energy are promoted by the hortative policy of central government and local governments, the allowance of government is important to increase the competitive power of PV production. And the Chinese central and local government should increase the research fund of PV to grasp the pivotal technology, such as circuit topology and MPPT control method and grid-connect. Moreover, the tax should be reduction or exemption by government, which will motivate the enthusiasm of entrepreneurs, and which will increase the PV market through government policy initiatives. The advantage of investors should be ensured by government policies. Certainly, the government fund should be launched in the vast power supply project in order to improve the energy structure in the foreseeable future. For example the large desert grid-connect power plant must be established. The ordinary investor and corporation cannot supply the vast fund in the desert grid-connect power plant domain. The devotion of government is obligatory.

(ii) Abundant fund and personnel should be launched into the interrelated research of PV, and the universities and graduate schools should be encouraged to research in solar energy. The cooperation between corporation and university should be enhanced in order to improve the research level. The student is trained by universities in order to supply enough persons with ability to cooperation. Certainly, international cooperation should be encouraged to improve the domestic technology by central government and local governments.

(iii) The PV industry chain should be established in order to enhance the economy benefit of Chinese PV industry. Especially, the lack of silicon material and pivotal technology should be settled in future. The PV market should be enlarged in order to digest large numbers of PV product. The attestation and detect organization lacks the contact with the international organization, and the criterion of whole industry should be established.

Acknowledgments

The authors would like to acknowledge the financing support of Chinese Postdoctoral Research Foundation (No: 20080440088), Shanghai Postdoctoral Research Foundation (No: 08R214134), Shanghai BaiYuLan Science and Technology Foundation (No: 2007B073), China Education Ministry Research Foundation (No: 20071108), Science Research and Development Program of Shanxi Province (NO: 200811026), and Youth Science Research Foundation of Shanxi Province (NO: 2009021020).

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